7th Asia-Pacific Conference on Plasma Physics, 12-17 Nov, 2023 at Port Messe Nagoya

SOLPS-ITER modeling of edge plasma and impurity transport in EAST

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The comprehensive SOLPS-ITER [1, 2] code package has been utilized to analysis drift effects on scrape-off layer (SOL) widths [3], e.g. the power decay length λq, and on the divertor detachment and asymmetry in EAST plasmas with favorable and unfavorable toroidal magnetic field (B_T) direction, i.e. with the ion **B**×∇B drift pointing towards and away from the active X-point.

To gradually highlight the role of the drift-based neoclassical mechanisms in the radial particle transport, the turbulent transport level (i.e. D_{SOL}) has been scanned from high (1.0 m^2/s) to extremely low (0.02 m^2/s). It is found that the drift-driven transport, considered as the key process in the formation of SOL plasma profiles, is magnetic-field-direction dependent and thus SOL flows and currents as well as the SOL widths can be obviously affected by the direction of drifts. With B_T changed from the favorable direction to the unfavorable one, the flattening of density radial profile as well as the increase of power decay length, in the SOL, can be achieved and can be further enhanced as the weight of turbulent transport (i.e. D_{SOL}) gets reduced, due to the increased contribution of ion parallel viscosity to the radial ion flow. Particularly, with $D_{SOL} \leq 0.05$ m^2/s in the simulations, the dominant role of drift-based neoclassical mechanisms in the radial particle transport will lead to the formation of the so-called edge density-shelf [4] in plasmas with unfavorable B_T. Power scrape-off width in plasmas with unfavorable-BT is much insensitive to the turbulent transport level and can remain to be relatively high even when D_{SOL} has been decreased to be extremely low. Due to the compressing/widening effect of the drift-driven inward/outward radial particle flow, the simulated power scrape-off width exhibits an in-out asymmetry, which is also magnetic-field-direction dependent.

Besides, drift effects on divertor detachment, asymmetry and impurity transport in the neon (Ne) seeded EAST plasmas with both B_T directions have also been investigated. Firstly, electrostatic potential/field distribution has been analyzed, which reveals that in favorable B_T divertor electric potential profile follows the classical picture; while in unfavorable B_T the so-called X-point potential well forms in detached plasmas, when Pfirsch-Schlüter currents dominate the parallel current, compressing/widening radial density profile in the inner/outer divertor. In the confinement region, it is found that magnitude of the radial electric field ($\boldsymbol{E}_r$) is close to its neoclassical value, and that $\boldsymbol{E}_r$ for unfavorable B_T is smaller than that for favorable B_T due to the smaller neoclassical contribution related to radial density gradient. In accordance with the experimental observations in EAST, simulation results demonstrate that in favorable B_T the onset of detachment is highly asymmetric between the inner and outer divertors; and the magnitude of in-out asymmetry in divertor detachment can be largely decreased by reversing B_T, physics reasons for which have been explored. It is found that, apart from the well-known $\boldsymbol{E}\times\boldsymbol{B}$ drift particle flow from one divertor to the other through the private flux region (PFR), heat flow through the SOL, particularly power flow from the upstream to divertor, is also a critical parameter affecting divertor detachment and asymmetry. In-out asymmetry in neon-seeding induced pressure loss along flux surface in the SOL tends to drive a convective heat flow from the hotter to the colder side, making upstream power flow into the colder divertor region more insensitive to neon seeding level. Besides, position of the stagnation-point for poloidal neon ion velocity profile, a key element determining neon leakage/retention in divertor, can be greatly affected by P-S flow direction, $\boldsymbol{E}\times\boldsymbol{B}$ drift and by divertor operation regimes depending on neon seeding level. Hence, leakage of neon from divertor is found to be much sensitive to neon seeding level and B_T direction. The former can also affect the neon ionization source distribution, as another key factor determining neon divertor retention/leakage.

References

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